



Armed Forces College of Medicine AFCM



Skeletal muscle metabolism

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INTENDED LEARNING OBJECTIVES (ILO)



By the end of this lecture the student will be able to:

1. Identify different energy sources supplied to the muscle
2. Describe the importance of each energy source system
3. Define the oxygen debt
4. Identify the types and the importance of oxygen debt
5. Identify causes of muscle fatigue
6. Identify muscle mechanical efficiency and thermal changes during contraction

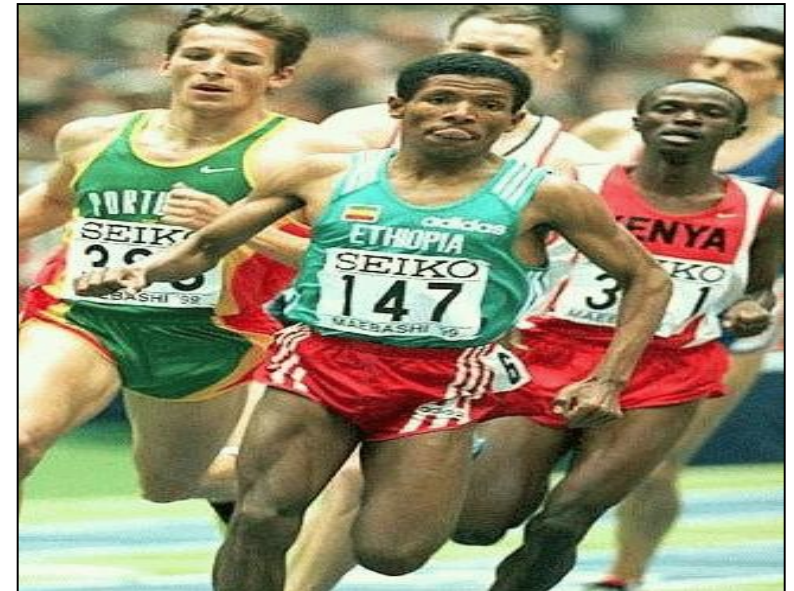
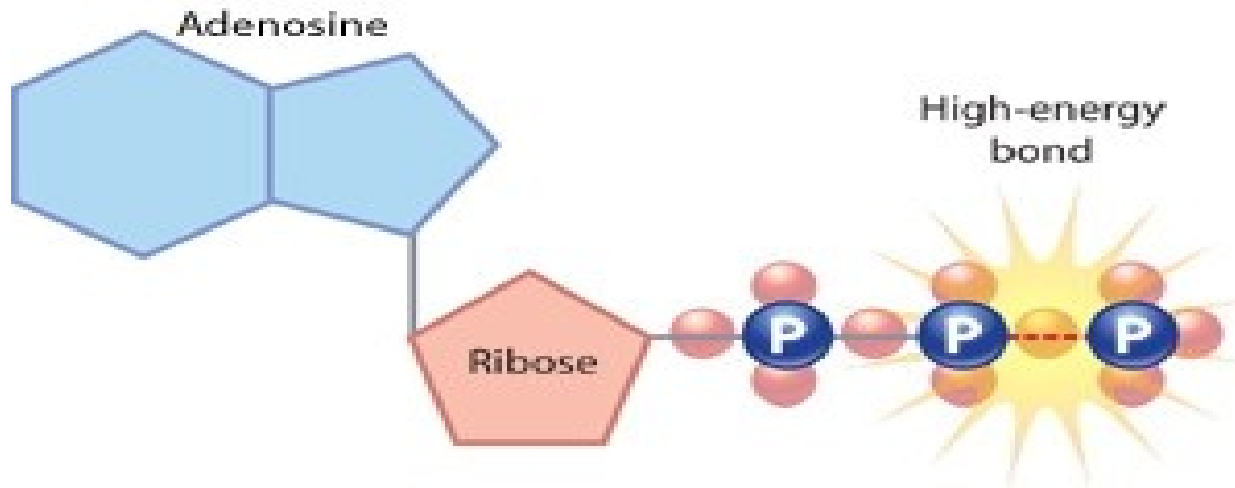
Lecture Plan



1. Energy sources introduction (10 min)
2. Importance of energy sources and their characters (30 min)
3. Summary (5 min)
4. Lecture Quiz (5 min)

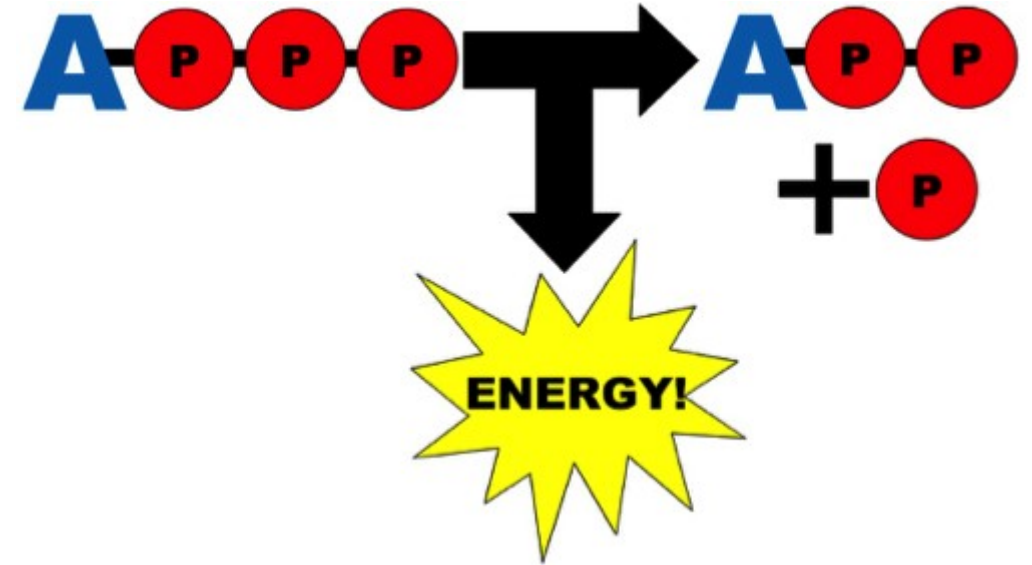
Muscle energy sources

- Muscle is a machine that convert **energy (ATP)** to mechanical work
- ***ATP (adenosine tri-phosphate) {energy currency}*** is the primary energy source for muscle contraction



Adenosine triphosphate (ATP)

- Contain terminal high-energy phosphate bond
- Hydrolytic enzyme (***ATPase***) **break** the terminal **high-energy** phosphate bond to **release the potential “stored” energy** in ATP
- Stored ATP is minimal and sufficient only for **few seconds** of contraction
- Muscle contain different pathways that regenerate ATP



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1: What are the regenerating pathways for ATP?

1) **Ultra-rapid immediate system**

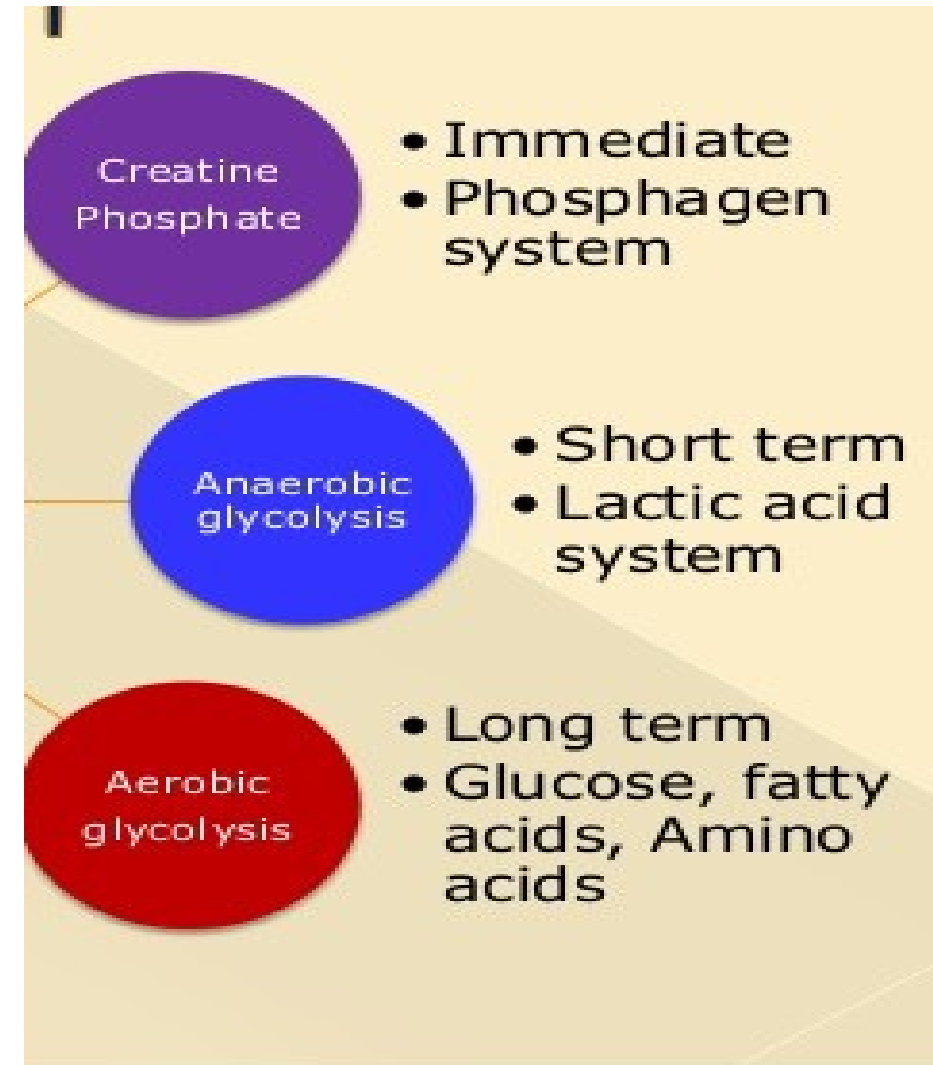
Hydrolysis of creatine phosphate.

2) **Short-term anaerobic system**

Anaerobic glycolysis.

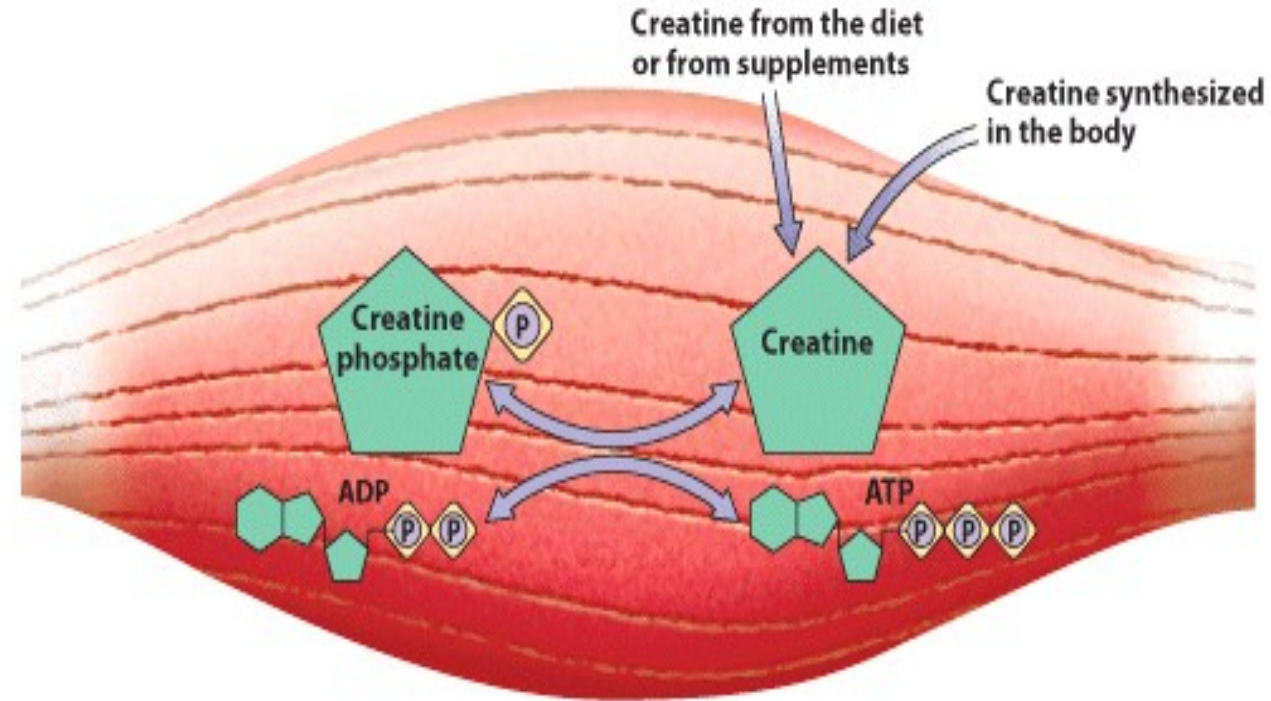
3) **Long-term aerobic system**

Oxidative phosphorylation.



2: Importance of : Ultra-rapid immediate system

- **One molecule ATP** is formed per **one molecule** of **creatine phosphate** by substrate phosphorylation
- Immediate energy source in the **first few seconds**
- **High intensity short term exercise** as:
 - High jump
 - Weight lifting
 - 100 m running



2: Importance of : Short term anaerobic system

- **Fuel:** **glucose** is broken by **anaerobic glycolysis (oxygen absence)**

- **Source:** directly from blood or from glycogenolysis

- **End product:**

2 ATP molecules+ lactic acid

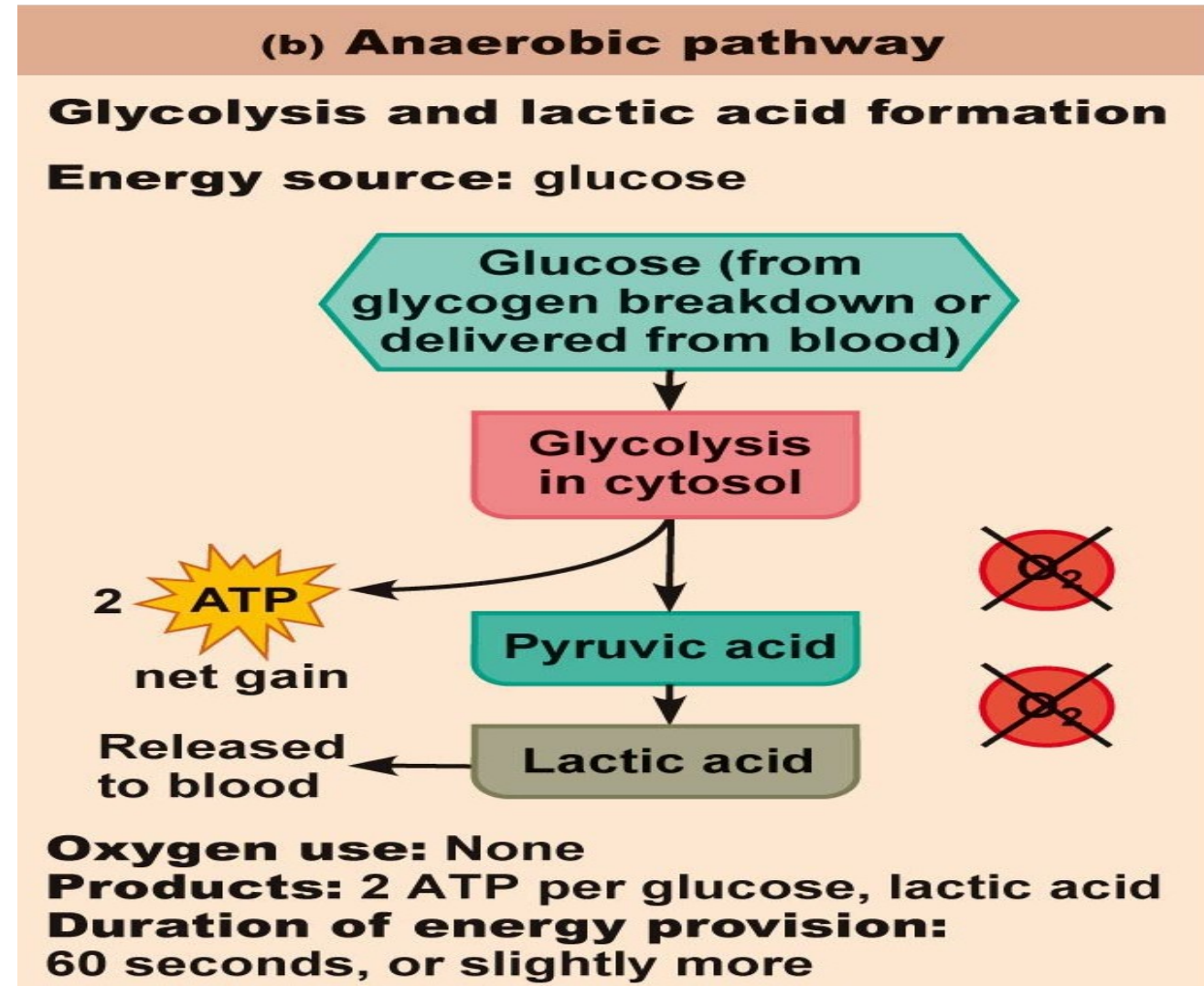
- **Importance:**

- **Produce ATP 2.5 times as rapid as oxidative pathways**

- **Few minutes at the start of exercise**

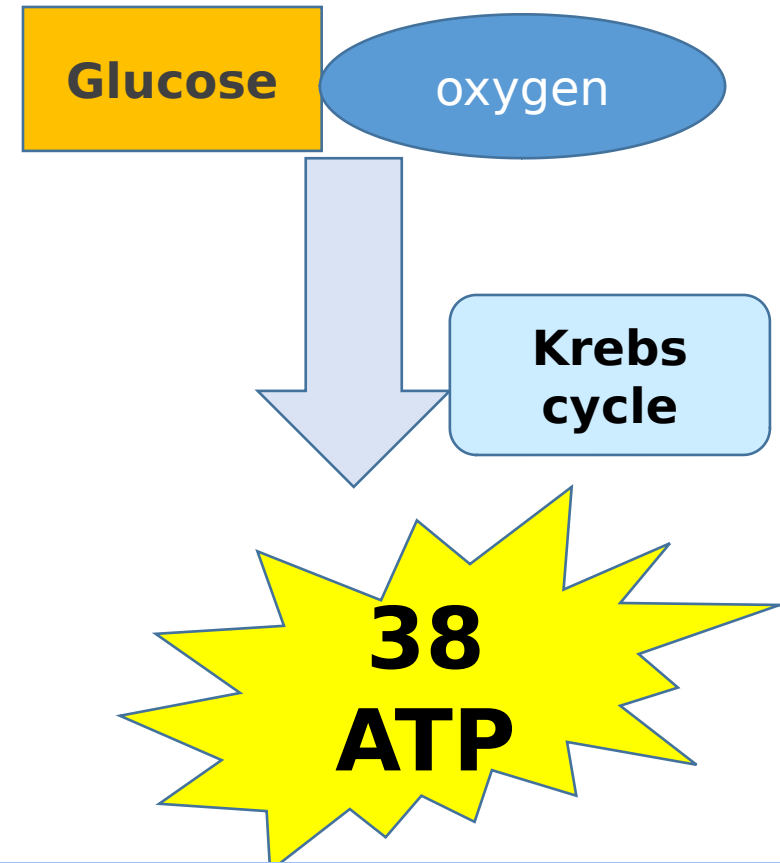
- **At the end of the prolonged exercise when the aerobic system fails**

- Excess lactic acid causes fatigue



2: Importance of : Long term aerobic system

- **Fuel:** glucose mainly
- **Oxygen source:**
 - Directly from blood
 - Stored in myoglobin (muscle oxygen containing molecule)
- **Aerobic endurance exercise or Light exercise**
 - Walking
 - Moderate exercise
 - marathon



❑ In prolonged light exercise more than 1 hour or in the resting muscle **free fatty acids oxidation** can supply energy

Short-duration, high-intensity exercise

Prolonged-duration exercise



6 seconds

10 seconds

30–40 seconds

End of exercise

ATP stored in muscles is used first.

ATP is formed from creatine phosphate and ADP (direct phosphorylation).

Glycogen stored in muscles is broken down to glucose, which is oxidized to generate ATP (anaerobic pathway).

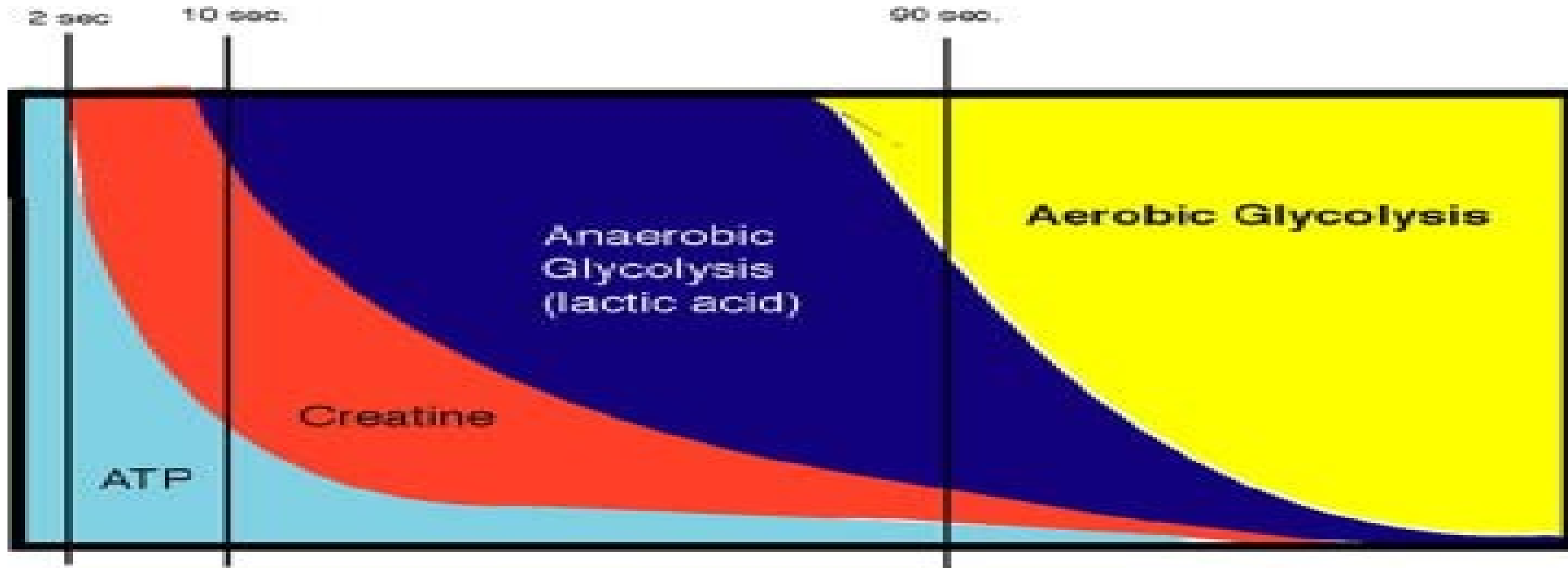


Hours

ATP is generated by breakdown of several nutrient energy fuels by aerobic pathway.

Dominant Energy Pathways for Exercise of Differing Durations

EXERCISE TIME → → → → →

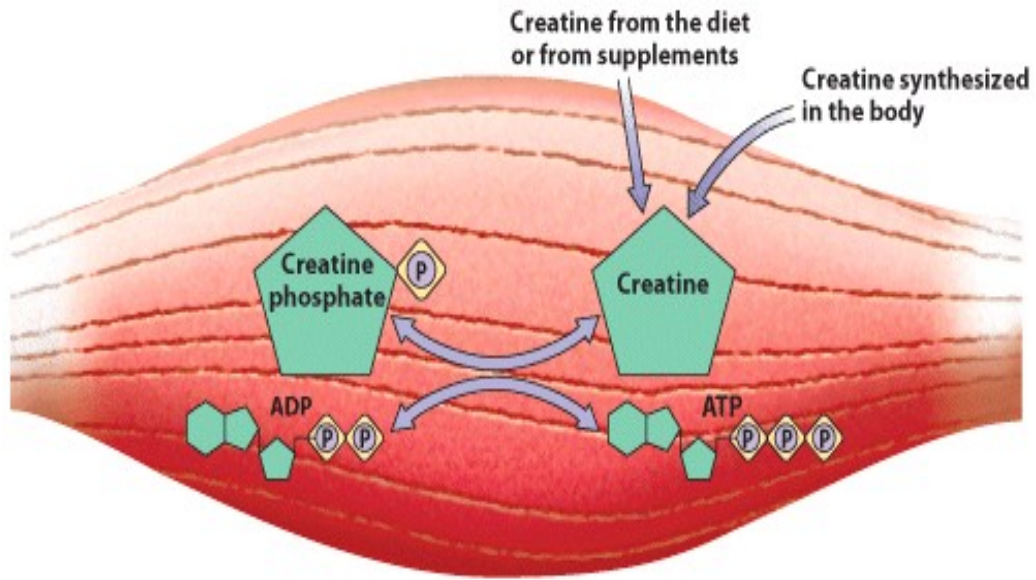


ANAEROBIC

AEROBIC

This athlete runs in a 100 m sprint race, what are the ATP sources?

- Ultrarapid immediate system



This man practices jogging every morning, what are the ATP sources?

- **Long term aerobic system**
- **Fuel:** glucose mainly
- **Oxygen source:**
 - Directly from blood
 - Stored in myoglobin (muscle oxygen containing molecule)



3: Explain the shift to anaerobic system at the end of exercise

- Because the aerobic system is unable to meet the muscle demands.
- So anaerobic threshold is reached

❖ **Aerobic power** depend on:

- The lungs' ability to oxygenate the blood
- The cardiovascular system's ability to deliver the oxygenated blood to the exercising muscles
- The muscles' ability to extract and utilize the oxygen to produce energy

Muscle fatigue

- It is the temporary decrease in muscle force of contraction due to previous contractile activity.
- **Causes of fatigue:**
- **A) Muscular fatigue:**
- Lactic acid accumulation: increase in the intracellular acidity and inhibit key enzymes in energy pathways.
- Energy stores depletion
- **B) Neuromuscular fatigue:**
- Acetyl choline depletion at the motor end plate during fast-powerful activities.
- **C) Central psychological fatigue:**
- Central nervous system no longer adequately activates the motor neurons supplying the working muscles.
- Athlete's performance is not only dependent on the physical state of his muscles, but also, upon the **well to win** "ability to overcome psychological fatigue".

4: What is Oxygen debt

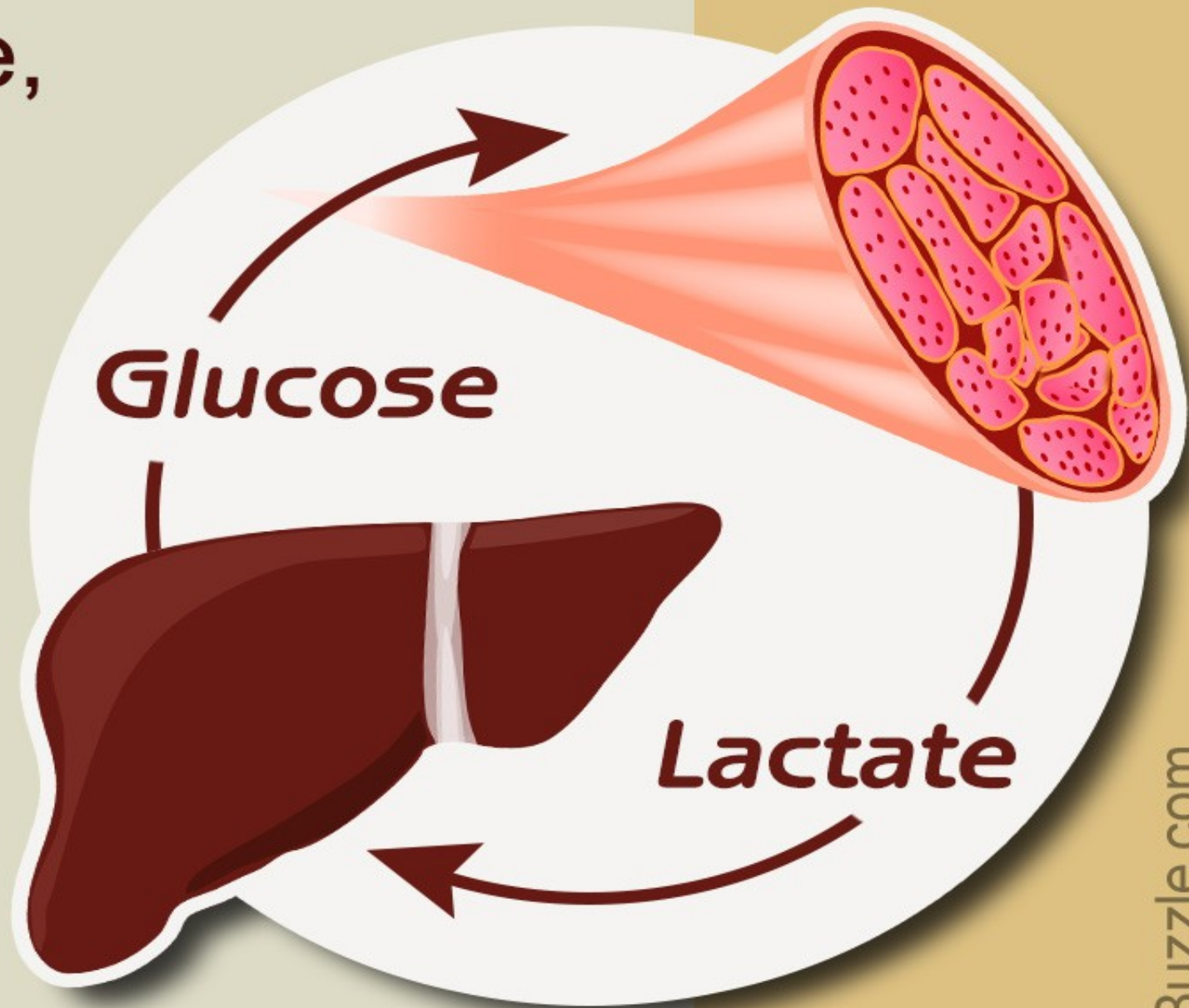
- **Definition:**
- Extra-amount of O₂ that must be taken into the body during recovery period after muscular exercise
- **Recovery period:** from end of exercise till the return of heart and respiratory rate to normal.
- **Aim** To restore all the metabolic systems back to their full normal state.

5:Types of oxygen debt

Lactic acid O2 debt	alactic O2 debt
Greater amount of O2	Smaller amount of O2
Takes about 1 hour or more	It is fully rapid within 2-3 minutes
<ul style="list-style-type: none">➤ Remove excess lactic acid from the muscles and all body fluid.➤ Convert lactic acid to pyruvic acid and glucose	<ul style="list-style-type: none">➤ Replenish ATP stores➤ Restore creatine phosphate (CP)➤ Rebind to myoglobin

In the cori cycle,
lactate

produced by
the muscles is
converted to
glucose
by the liver,
and fed back
to the muscles.

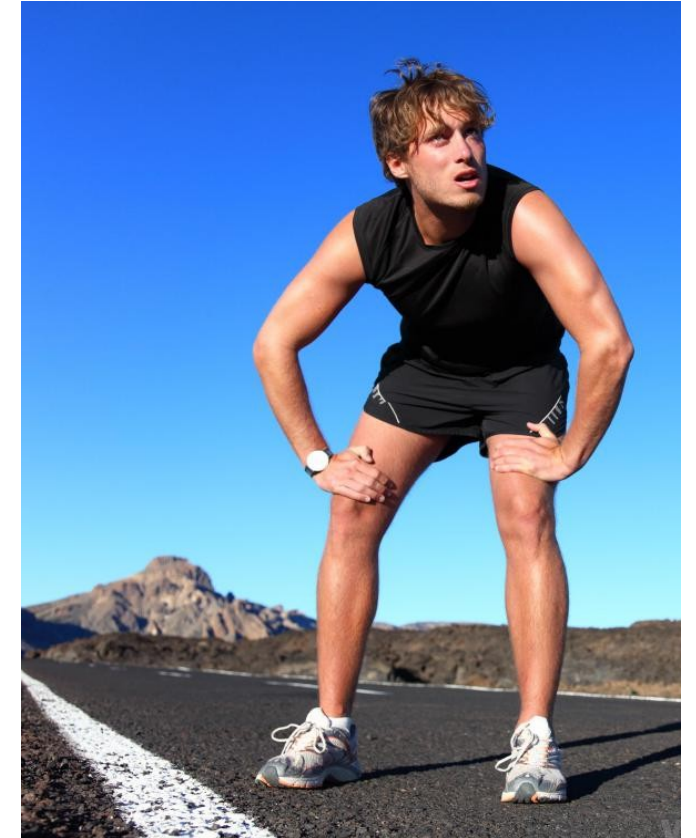


What are the causes of this un comfort breathing ?

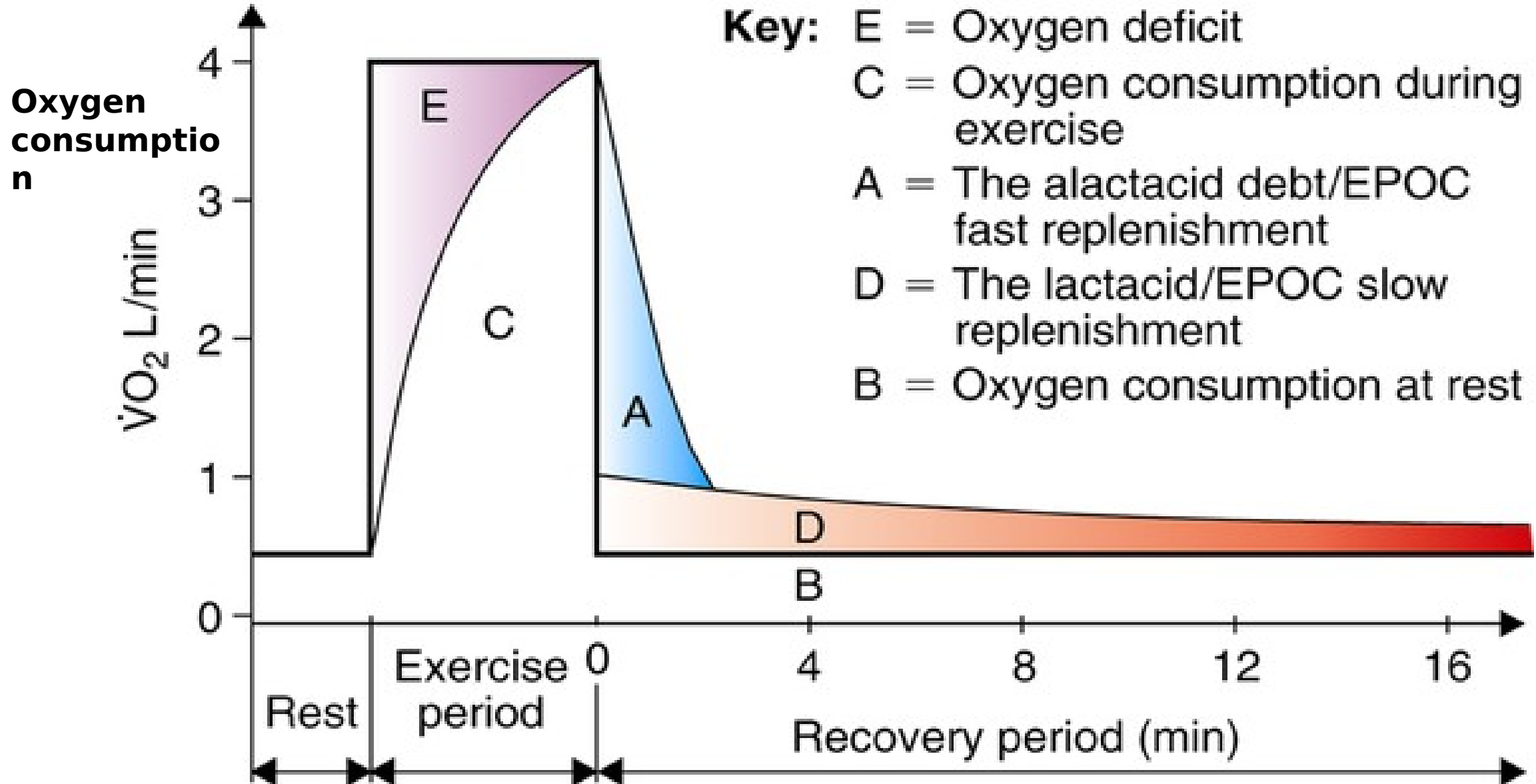
- Extra-amount of O₂ must be taken into the body during recovery period after muscular exercise, this is called oxygen debt.

Suggest a method to decrease oxygen debt

Training



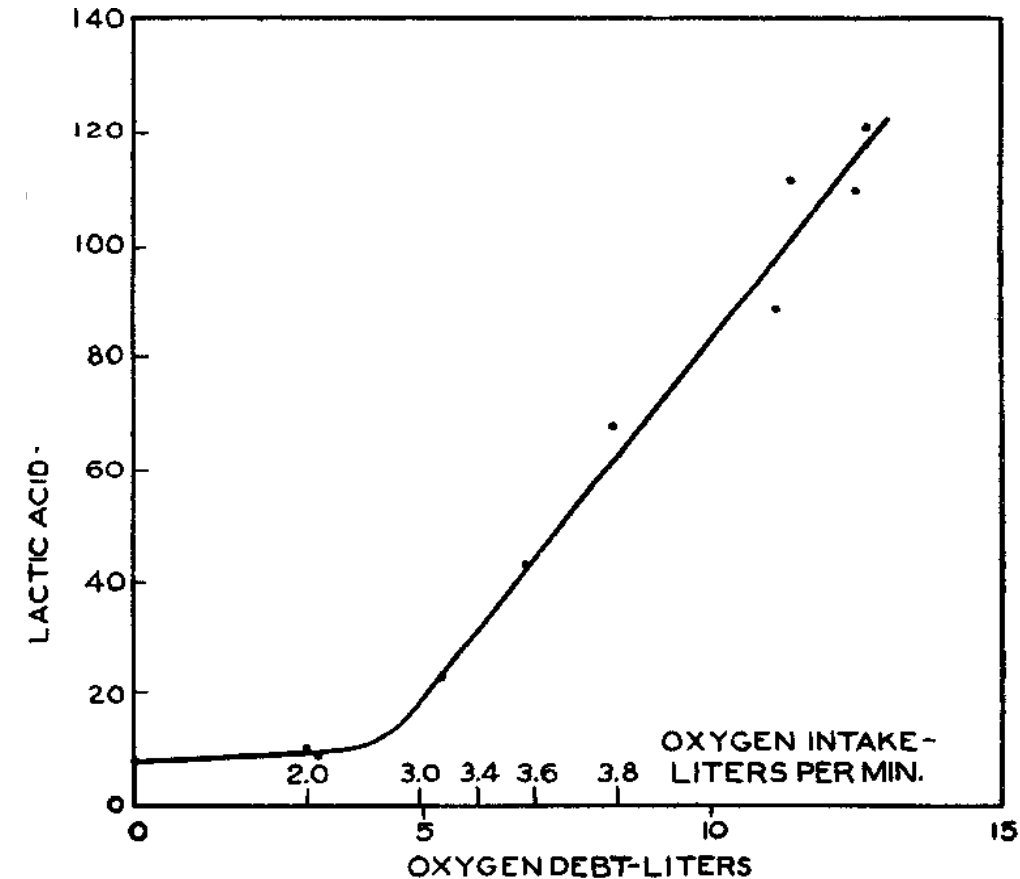
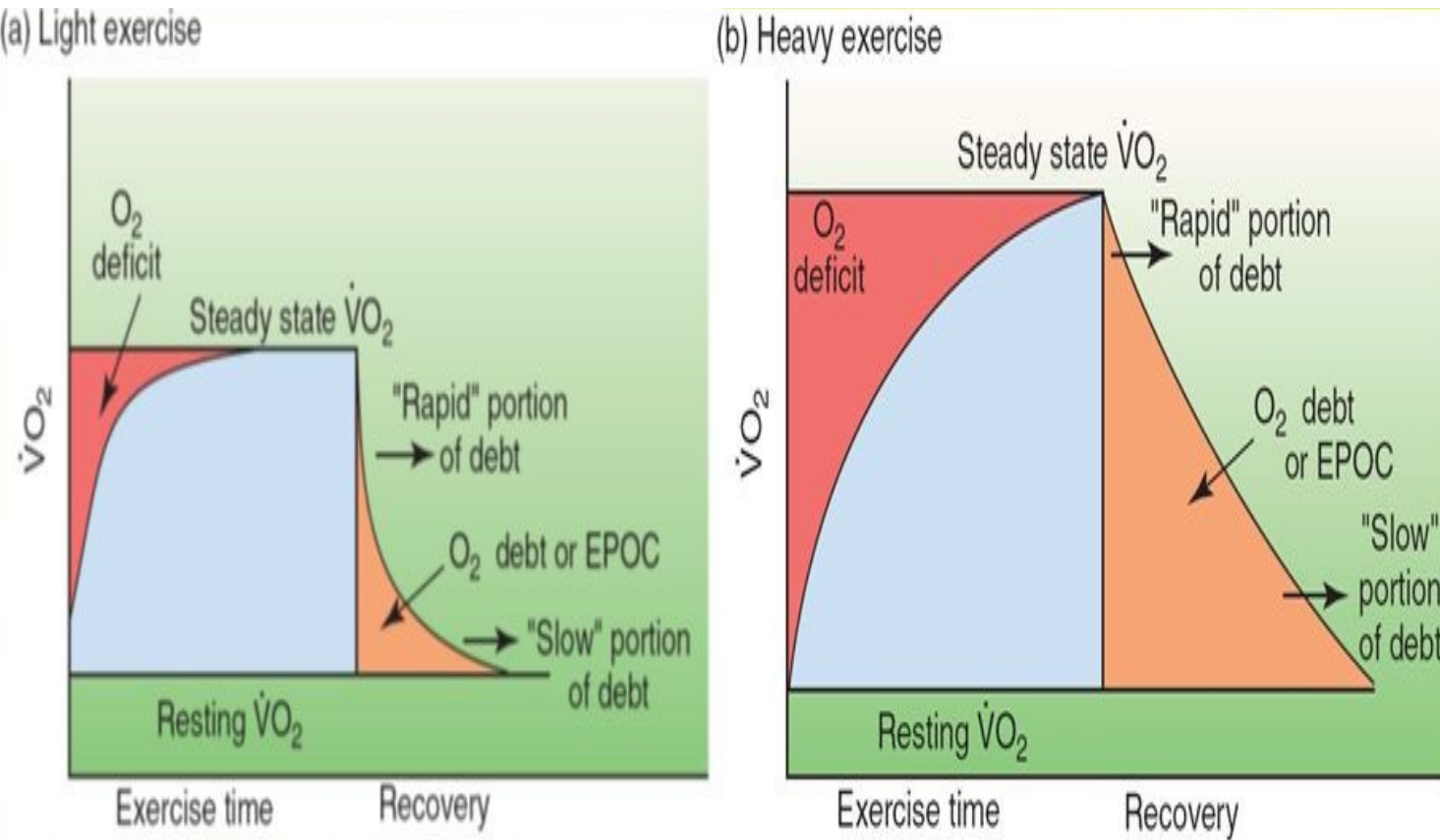
Oxygen debt pay for the oxygen deficit



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Oxygen debt pay for the oxygen deficit

Note: Trained subjects have lower oxygen deficit due to better aerobic capacity, less lactic acid production



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<https://images.app.goo.gl/Yem6RgfMeWkyk9Xt7>

6: List the thermal changes during muscle contraction

During rest External manifestation of basal metabolic processes.	Resting heat
Heat in excess of resting heat during contraction Divided into: a - activation heat that is produced during contraction b- shortening heat: which is proportionate in amount to the distance the muscle shortens	Initial heat
Heat in excess of resting heat during recovery continues for 30 min Heat liberated by the metabolic processes that restore the muscle to its pre-contraction state = Initial heat	Recovery heat
Restore muscle length after isotonic contraction	Relaxation heat

Summary

- ATP is the main muscle energy source
- Exercise first few seconds: Ultra rapid phosphagen system.
- First few minutes or at the end of the exercise: short term anaerobic system {anaerobic glycolysis}
- Long term endurance exercise: aerobic glycolysis
- Oxygen debt: Extra-amount of O₂ that must be taken into the body during recovery period
- A lactic oxygen debt rapid to replenish ATP, CP and myoglobin
- Lactic oxygen debt prolonged to remove muscle lactic acid and convert it to glucose
- Mechanical efficiency = $\text{Work done} / \text{Total energy expended} \times 100$
- Resting heat, initial heat, recovery heat, relaxation heat



Put T or F

1. The lactic oxygen debt is restored within minutes
2. Isometric contraction mechanical efficacy is 100%
3. Creatine phosphate is used in the first few seconds of contraction

1 F
3 T

2 F

SUGGESTED TEXTBOOKS



1. Ganong review of medical physiology, 25 th edition,
chapter 5
2. Fox human physiology , 14th edition, chapter 12

Well done

